ARTICLE

Sustainable Water Resources Management of the Nile River, Egypt

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Keywords: sustainability, the Nile River, Egypt, integrated water resources management, indicator/index, scenario

1. Introduction

1.1 Background of the Nile River

The Nile River is known as the longest river in the world with a length of approximately 6,700 kilometers. Its two main tributaries are the White Nile originating from the Lake Victoria Basin and the Blue Nile having its source on the Ethiopian Plateau (MWRI, 2005). Throughout a long history, this river is currently serving eleven riparian countries. Unfortunately, as a shared water resource, conflicts happen time and time again in this region. Egypt, a country located at the lowest basin downstream of the Nile River with little precipitation, highly relies on the water resources from the upstream. According to the Ministry of Water Resources and Irrigation (2005), 87% of the available water resources come from the Nile aquifer. In addition, the climate change is estimated to further aggravate the conflicts in the manners of "uncertainty in precipitation and river flow, land degradation, reduced river flow, floods, siltation, waterweed infestation, wetland degradation, droughts, deforestation, loss of species and ecosystems and increased incidence of disease" (UNEP, 2011). The rational and sustainable way for the management of the Nile River has always been taken serious consideration of. As for Egypt, the development of water management at national level was shown in the following figure 1. Apparently, the artificial management instruments has varied and gradually constructed a system to sustain the water environment.

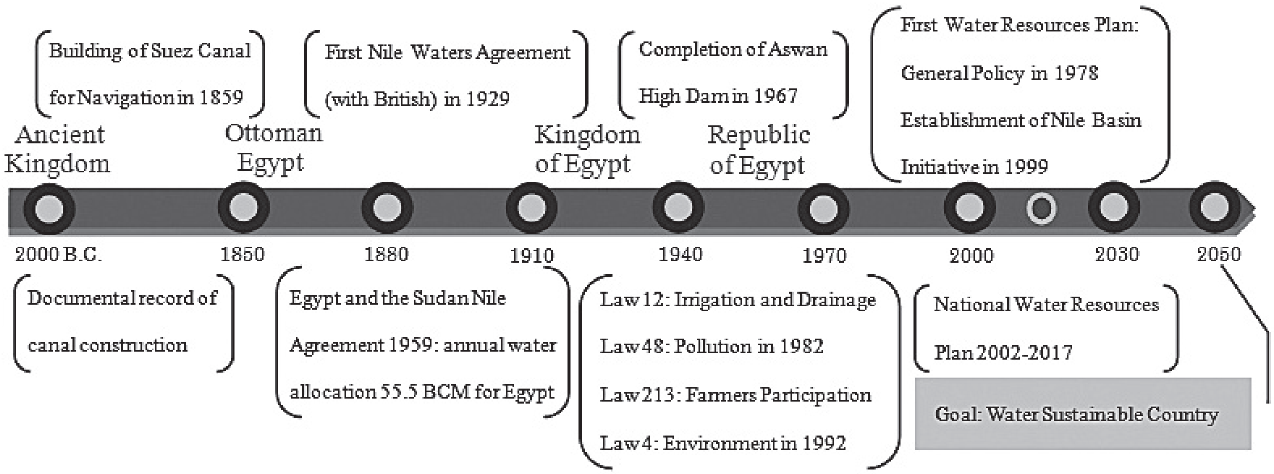

Figure 1. Events of Water Management in Egypt

Note: This figure is made according to information from work of Larry (2010) and national water resources plan by MWRI (2005).

In modern years, the colonization around the Nile River triggered perennial agriculture, and the years of artificial water management started. This period ended in 1953, with many cross-border agreements reached. Some agreements are still effective nowadays, while others would have to be reconsidered. The independent water regime along the Nile River has been remarkably developed after the colonization period. Because the resources of the Nile River depend on a variety of factors both externally and internally, the management of water resources by each country is of vital importance as well.

1.2 Water Sustainability

Sustainability became a hot word after the publishing of Our Common Future by Brundtland (1987), and has gained its application in some fields like policy-making and management strategies. In 1990s, its application expanded much broader fields at different levels, such as economic sustainability, environmental sustainability and, even more specifically, water resources sustainability. The sustainability of water resources refers to the water resources system that "designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological environmental and hydrological integrity" (Loucks and Gladwell. 1999). This concept indicates that sustainability relates to more than one aspect. Besides, it is dynamic, rather than static. Therefore, the methods for realizing water sustainability should take these aspects into consideration. Savenije and Van der Zaag (2008) came up with a conclusion regarding the development of integrated water resources management, and stated that integrated water resources management contains three of four dimensions, i.e., natural side, human side, different spatial scale and temporal scale variation. Under this condition, Bedrich, et al. (2012) discussed that a wide range of indicators helps to quantify the "sustainability" and ease the measuring process to the ideal sustainability "target". The indicator-based assessment method is widely used for the evaluation of sustainability including the water sustainability. The Water Poverty Index (Sullivan, 2002) and Watershed Sustainability Index (Chaves and Alipaz, 2007) are examples of global water sustainability indexes. As for regional indexes, Canadian Water Sustainability Index(Policy Research Initiative, 2007), West Java Water Sustainability Index(Juwana, et al., 2010) and the application of Watershed Sustainability Index(Ana Elizabeth, et al., 2012) represent the fitness of this method for measuring sustainability.

The indicator-based method indicates the “integrity” characteristic of sustainability concept. Nevertheless, the dynamic movements in long-term could not be reflected at all. Fortunately, studies concentrating on long-term performance came up with a new tool, i.e., the scenario-based method. Since the water shortage problem is ringing the alarm around the world, scenarios of water supply and demand have been developed. A global-level study designed two scenarios from the year 1990 to 2025, based on different irrigation efficiencies, and the result of which clearly showed that the improvement of irrigation effectiveness could save approximately one-half of the additional water resources (David, et al., 1998). Another paper was conducted at a national-level in Egypt (Mohamed and Gamal, 2007), with a conclusion regarding the challenges and opportunities for Egypt from the year 2000 to 2020. This research designed three scenarios based on different development speeds, and the result showed that ‘faster speed of development’ water policies promoted the effectiveness of water system and could lead to a sustainable future.

1.3 Research Objectives

As the current water resources plan in Egypt will expire in 2017, the proposal of a new version is in urgent need. Aiming at contributing to the sustainable management of water resources in the long run, this study was carried out in the following three steps. Firstly, a water sustainability index system was developed exclusively for Egypt, by comprehensively taking the aspects of ‘resource’, ‘environment’ and ‘socio-economic’ into consideration. Then a future scenario of water supply and demand in Egypt was designed, still based on this water sustainability index system. Finally, the sustainability indexes were calculated and compared time-wise (i.e., past, present and future). Policy recommendations were briefly described accordingly.

2. Study Area and Methodology

2.1 Background of Water Management Plan in Egypt

After the establishment of Arabic Republic of Egypt, there were officially two national water resources implemented. A National Water Resources Plan resembles the awareness of water problems at state level. Meanwhile, it leads the further direction of water management. Thus, the two national plans had consistency and variation at the same time.

The General Policy released in 1978 by The Ministry of Irrigation (at that time) was the first official plan on management and development of water resources. It focused on the agricultural water use problem and made adjustments on institutional aspects as well. Generally, it was a series of policies including, irrigation and development and water management policy, water resources for Horizontal Projects, drainage policy and irrigation development policy, that all of these inaugurated from the Water Policy discussed in 1975. This water resources plan compared the real irrigation water consumption which was 51,408 milliard ㎥ in 1974, with the availability of water resources 68,168 milliard ㎥ and found that there was tense on accessing water annually. Consequently, the government officially raised the improvement of water efficiency as a problem to be solved. As the solution, there were eight general policies separated in two stages working against it from irrigation, drainage and underground water aspects. In the detailed scope of preserving irrigation water and its rational utilization, problems of leakage, soil deterioration and extravagancy were brought out. To solve these problems the Rational Irrigation Water Utilization Plan was implemented in 1975. After two years, the achievement revealed as a partial reduction of water extravagancy and a 7,500 million ㎥ increase of the available irrigation water. At the same time, in order to develop the irrigation system, canal and drainage networks were built as 55,000 km long, 70 million ㎥ volume. The pattern of night irrigation was also discussed which aimed at conversing from flood irrigation to surface irrigation, and sprinkler irrigation. In addition, companies supplying mechanical machines and technological help were launched for improving the efficiency. Those cultivated land projects were included in the policies to improve the drainage network and production. Government encouraged drainage-related business, such as keeping cement business share at 14,000 tons/month and importing materials at 7,000 tons/month. For connecting the drainage and canal networks with agricultural projects, the fundamental construction was considered as well, for example, construction of pump stations, electricity support, and renewal projects. At last, the policy made administrational adjustment at both national level and regional level, in order to encourage scientific researches supporting the water resources management, and to reach more rational legal and organizational management on water resources.

The second plan was promulgated in 2005 which included the policy contents between 2002 and 2017. This national plan raised the awareness of water problems. It was of vital importance to pursue sound water resources management in Egypt, such an arid country with negligible amount of precipitation. Relatively, it was more comprehensive and a goal-directed plan compared to the 1978 version. The ultimate goal of this plan was to provide guidelines for both public and private actions in the future so as to ensure optimal development. The policies were designed according to the principles of Integrated Water Resources Management (IWRM), which the Ministry has taken the following definition among all: a process that promotes the coordination in development by managing water, land and relevant resources, for the purpose of maximizing the optimal economic and social conditions without sacrificing the sustainability of natural ecosystem (GWP, 2000).

The principles indicate two dimensions. First is to aware that water resource is finite and vulnerable resource; second is to accept that the trend of problem solving must take participatory approach into account. Water related information is categorized in three different systems, i.e., Natural Resources System, Socio-Economic System and Administrative and Institutional System; and the combination of these three is defined as Water Resources System (MWRI, 2005). At the very beginning, the national plan defined the challenges of Egypt from three dimensions: growing population, limited supply and pollution. Next, it set the "Facing the Challenge" strategy to solve the problems positively. But constantly, some of the projects like the horizontal expansion plan of agriculture started from 1975 are still working now. Thus, the current water plan is operating as a transition from past plan to an integrated management.

The national plan was consisted of six chapters with detailed description of the country and policies. In Chapter two, the current situation was concretely and separately described in three systems. Policy context was reported in the Chapter three based on the facts, and they were analyzed in Chapter four to clarify the advantages and limits. The main idea was to efficiently use the available water resources, while exploring other way to increase the supply so that the development goals in socio-economic aspects would be achieved. The Chapter five provided the policy decisions on improving efficiency, exploring additional supply and protecting public health and environment. The last part of national plan gave a framework of each stakeholder for implement the actions in situations according to this plan.

Both of the national plans were emphasizing agricultural water use and supply, which was understandable since nearly 80% of the water resource were consumed in agriculture (MWRI, 2005). This action was a symbol of transformation from traditional management to demand management.

However, the plan in 1978 was a start and a rough guide for fundamental constructions of water resources management. It started with concluding the facts of supply at that moment and combined the facts with agricultural situations. The scientific studies also started contributing to the policy making processes. The accuracy and scale of the above aspects were far more improved in the national plan of 2005. The 2005 version had a very important improvement that it introduced the IWRM concept. It was applied to both the domestic management and international cooperation. Compare to the past plan, the management of water considered the balance between demand and supply for socio-economic goals, rather than simply calculated water allocation. Studies on the water problems became diverse and comprehensive through years. Since the current plan will be executed till 2017, the next step of water management is under way. The consistency of the next plan with the past ones is regarded as the concept of IWRM. The challenges that escalate in scale emerges the consideration of balance between diverse demand and limited supply in Egypt. It is regarded as the origin of water problems in Egypt in deed.

2.2 Methodology

For overcoming the weak points in the previous plans, an original water sustainability index system was developed exclusively for Egypt, with an indicator-based (index) assessment method and an elaborate scenario describing water sustainability in 2050.

Water sustainability index system for Egypt is the aggregation of three components: resource, environment and socio-economic development with several related indicators (see Table 1). Development of index consists of five steps according to Juwana's work (2012) they are selecting indicators, normalization, weighting, aggregation and interpreting. Monldan B., et al. (2012) stated that the selected indicator once defined has to be "measured" in both quantitative and qualitative sense. They also informed that the long-period indicator can be used to understand the trend. Thus, this paper selected nineteen indicators, divided in the three groups. First group contained the indicators related with various water supply amount and percentage of access that shared the component called "Resource". The other important component for water sustainability was natural and social "Environment". This component described the water quality and the influence of water use. The last component was "Socio-economic" group. This group indicated how the basic artificial factors act on water sustainability. During the selection of data, twelve were obtained from the Egyptian Central Agency of Public Mobilization and Statistic, four were drawn from the published data of World Bank and the last two origin data were the indexes developed by UNDP. Details of structure and original data of this paper are shown on the following table.

The normalization of data aimed to remove the units of original data for later processes. The normalization method of each indicator was based on their data characteristic. For the first two components, quantitative data were having their ranges and the socio-economic components valued the development and showed no limits on number. Thus, according to the Juwana (2012) it was proper for applying the "continuous re-scaling" method for first two components and "Percentage of annual difference over two consecutive year" for last components.

The available time-series official datasets enabled this method and meanwhile a participatory method such as Analytical Hierarchical Process was not available currently for this study. Thus, the assumption of applying principal components analysis was commitment of the linear relationship among indicators within groups, and it was accordant with the main idea of this study. And the final water sustainability index was calculated with the following equation.

Table 1. Structure of Water Sustainability Index and Scenario Data

Component	Indicator	Data (year)		
		2005	2010	2050
Resource	Water Supply, $m^3 \cdot y^{-1}$	69×10^{10}	73×10^{10}	78×10^{10}
	Evaporation Loss, $m^3 \cdot y^{-1}$	2.1×10^{10}	2.1×10^{10}	1.9×10^{10}
	Sanitation Condition, %	92.6	94.9	98.0
	Water Level in Nassar, m	174.89	173.18	174.00
	Access to Water, %	98	99	100
	Drainage Condition, m^3	50×10^{10}	60×10^{10}	70×10^{10}
Environment	Dissolved Oxygen (DO), $mg \cdot l^{-1}$	6.77	7.01	7.50
	Chemical Oxygen Demand (COD), $mg \cdot l^{-1}$	13.05	10.02	9.00
	Biochemical Oxygen Demand(BOD), $mg \cdot l^{-1}$	4.66	3.52	3.00
	Total Dissolved Solids(TDS), $mg \cdot l^{-1}$	248	266	190
	Water for Drinking, $m^3 \cdot y^{-1}$	1.15×10^{10}	1.35×10^{10}	1.70×10^{10}
	Water for Agriculture, $m^3 \cdot y^{-1}$	59×10^{10}	61×10^{10}	62×10^{10}
Socio-Economic Development	Population	7.2×10^7	7.8×10^7	12.7×10^7
	Income Index	0.671	0.701	0.880
	Human Development Index (HDI)	0.645	0.678	0.800
	Gross Domestic Product (GDP), US Dollar	9.0×10^{10}	2.0×10^{11}	3.5×10^{11}
	Educational Investment, L.E	2.6×10^{10}	4.9×10^{10}	7.2×10^{10}
	Net Agricultural Income, L.E	1.0×10^{11}	1.8×10^{11}	2.5×10^{11}
	Cultivated Land, Feddan	8.4×10^6	8.7×10^6	9.0×10^6

Note: the data of the year 2050 is based on the designed scenario.

$$\textit{Water Sustainability Index for Egypt} = \sum_{n=1}^{19} (a_n x t_n)$$

Where,

a_n = weighting of each data, and

t_n = the year of data

For each indicator, data were collected from year 2005 to 2010. This dataset was processed to obtain the current water sustainability index. However, as to the future of Egyptian development, a scenario storyline was introduced for the long-term purpose. This paper assumed a relatively conventional development of Egypt with a negative climate change influence on natural resource. The water supply would relatively keep the same level after 30 years for two considerations. First, the IPCC Fifth Assessment Report included the result that 22% of water shortage in northern Africa is due to climate change according to Droogers et al. (2012). Second, the water conflicts along the Nile must be rather tensive because of the uncertain climate. However, because the technology of water recycle and distribution system would be developing as well, so the total supply is not decreasing. And by 2050, the water quality would alway be at a better condition. Population that accessing to water reaches 100% but 2% specific region is not supposed to have sanitatory water for use. The development of society is rather conventional than a rapid one. However, notable education investment and income level are highly improved to reduce the poverty and to realize the Millennium Development Goals in Egypt. GDP of Egypt is supposed to be increased at a limited speed. This scenario suggested a possibility of Egypt smoothly developing under a water resources shortage condition, and the result of water sustainability under this scene is showing in the next chapter.

3. Results and Discussion

The water sustainability index system consists of three components which describes the water supply, water related environment and basic socio-economic conditions. The absolute value of index shall be under three always. Because of the long time shift between 2010 and 2050, the year 2025 was also included as a reference. The water sustainability indexes of the year 2005, 2010, 2025 and 2050 (the designed scenario) are shown in Figure 2.

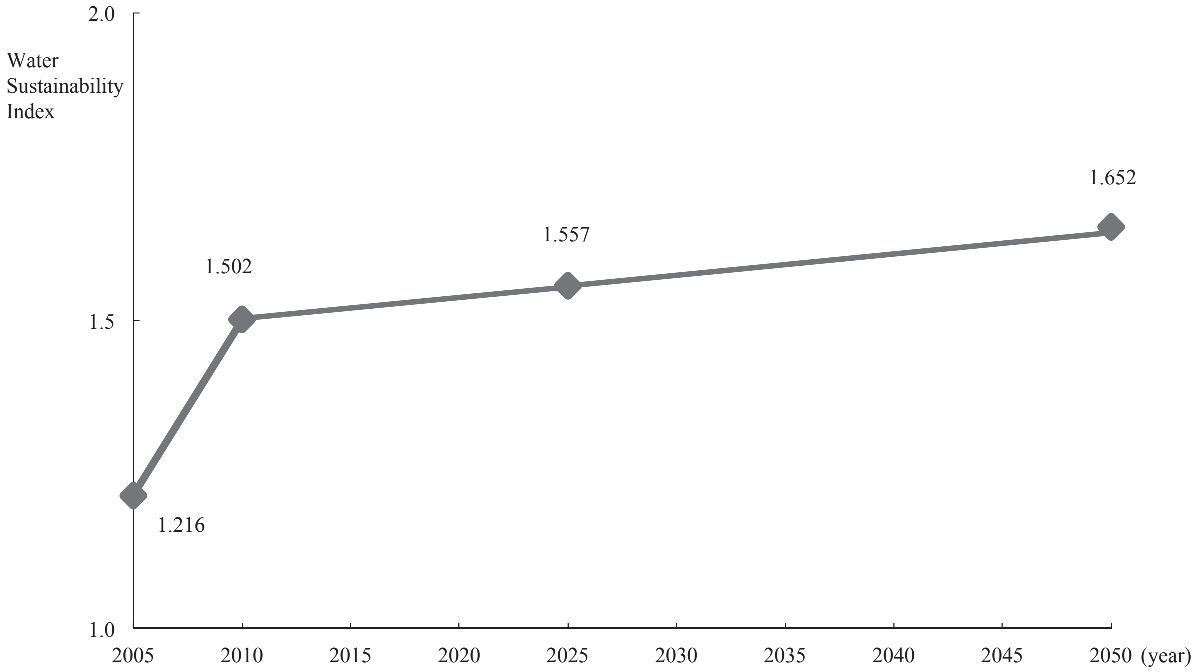

Figure 2. Water Sustainability Index for Egypt in 2005, 2010 and 2050

In general, an increasing trend of water sustainability was observed, with a fast improvement stage (from 2005 to 2010) and a relatively stable stage (from 2010 to 2025 and 2050). Since the absolute water sustainability index for Egypt is 3, the current level is right on the middle class of total. The higher the scores are, the harder to reach. Whereas, it must be noted that index can only reflect the state at a specific time, rather than describes the development process. Therefore, this result does not ensure that water sustainability has always been developing smoothly during the 40 years. The data in 2025 revealed almost the midpoint of development from 2010 and 2050. The data of 2025 matched the results of various previous study on estimation of water resources condition of Egypt which stated the water supply would be 72.4 Billion Cubic Meter (BCM) and the consumption of water in agriculture would be 61 BCM among all (Abdel-Shafy and Aly, 2002). The important thing is how the positive trend could be maintained till the year 2050 as what this figure shows or even become better than the estimated situation. Besides, it is also of great concern that we figure out which factors could have potentially negative influence that hinders the positive development trend.

In terms of each component, they are interdependent while separately influencing the water sustainability system. For resource component, it contributed to the most increase of water sustainability from 2010 to 2050 according to the story. Though the scenario did not suggest much additional water supply, but as population of water and sanitation water access improved the water sustainability level has improved as well. The ways of realizing this population cover rate are different depending on the environment. Since the improvement of safe water access rate belongs to one of the Millennium Goals, World Health Organization has been operating its programmes solving this problem. The main idea is to have and monitor "basic sanitation" which refers to the lowest-cost of technology used for water supply and collection pipes at home and in the neighbourhood (WHO, 2009). Usually, For Egypt, to have more efficient water distribution and drainage system at the mega-regions and scattered water distribution and collection points in the detached rural area are highly recommended. The total water supply in this scenario story was not increasing much but not dropping either, so that the possible water shortage problem is partially released.

The environment component almost stays at the same level from 2010 to 2050. The index in 2050 of environment group is 0.66 while the score of 2010 was 0.6. Current high water quality level of Egypt accounts for this steady development. The only one deficient in the water quality is Chemical Oxygen Demand (COD) concentration. As a result, the improvement of water sustainability in Egypt for the later years should focus on the water pollution problem especially on the COD containment. As a signal material of industrial and domestic wastewater, current COD concentration is highly related with the fast development in Egypt. To build a better water sustainable environment, the wastewater treatment processes onsite or collective should necessarily be enhanced as well as the legislation system. This requires high participation of public in the ideal situation, but can be realized by pushing from the top. China is applying a rather compact policy system which sets five years as the unit to achieve a goal. And the pollutant control for clearer water which includes COD pollution was included in the 2006 to 2010 plan and achieved a constructed result (Junjie, et al. 2011). The other two aspects of water use were assumed to increase since the demand of society extended. Water use tells the social environment of water sustainability. The scenario described a small increase in agriculture which could be interpreted in two ways. First, the agriculture of Egypt meets it limitation in the next 35 years and the water sustainability on agriculture also meets the limitation. The other way of thinking is that the efficiency of agricultural water use improved. The irrigation system and recycling system are the two aspects that could be improved. If the advanced irrigation system and recycling system are established, the score of the first component will be added in forms of total water supply increase.

The last socio-economic development component values the changes of human world. Since the ecosystem water consumption is ignored here, human is the only consumer in this study. The result of weighting process implied that the GDP growth rate and cultivated land variation were positively supporting the water sustainability. GDP growth has been a basic evaluation standard of country's development. To maintain the water sustainability is inevitably related with economic support. The outputs of economic support are diverse from software to hardware in a water system. The maintenance of equipments and facilities at regional level or national level is eventually a fiscal problem of government. However, the scenario supposed the country developing at a slow pace that may hardly influence the water sustainability. On the contrary, the result shows that only a rapid development of society will directly and largely influence the level of sustainability. WHO and many developed countries is making efforts to solve the poverty problem by especially paying attention to education of the rural women and children, which means income level and education matters water sustainability as well. But the behaviour of government on solving the poverty problem should be consistent. Thus, the cooperation between international aiding programs and government leading programs should be carefully operated. The same showed on the education investment indicator. A worse aiding policy could leads to inconstancy of development in a region that will negatively influence the water sustainability.

4. Conclusion

In the path of chasing water sustainability, integrated water resources management is a promising tool for Egypt. This study was a trial of putting this notion into practice. Taking advantage of indicator-based method, a water sustainability index was developed for the sake of comprehensively evaluating the water resources conditions in the past (year 2005) and at present (year 2010). In addition, a development scenario of the year 2050 was built so as to estimate the water sustainability of Egypt in the future. In general, the result displayed an increasing trend of water sustainability, with a fast improvement stage from 2005 to 2010 and a relatively stable stage from 2010 to 2050. In spite of this relatively positive phenomenon, how to maintain and even upgrade water sustainability of Egypt is of vital importance. Efficient actions could be taken from several aspects. Firstly, the coverage rate of the total population with access to sanitary water must be further improved, despite the satisfactory overall accessibility to water resources. It is suggested that onsite facilities be provided to decentralised regions, as well as cooperation with relevant enterprises be prompted. Secondly, water quality must be enhanced, especially the control of COD concentration in water bodies is of great concern. Onsite treatments are highly recommended for sources of effluent discharge, such as industrial plants. Last but not least, rapid development of the entire country could contribute to a better water sustainability, as long as the precondition is fulfilled, i.e., the formulation and implementation of effective policies and strategies towards successful integrated water resources management. In all, this study practised a quantitative assessment and estimation of water sustainability of Egypt in a 45-year span, through a combination of the indicator- and scenario-based methods. The result is considered useful reference for relevant water management and policy-making processes.

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